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DELTA ARRAY SENSOR DEVELOPMENT DEEP OCEAN TESTS.(U)
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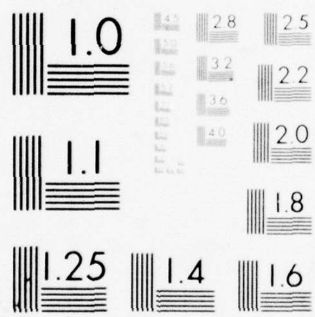

MICROCOPY RESOLUTION TEST CHART
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DEEP OCEAN TESTS.

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DELTA DEEP OCEAN TESTS

SUMMARY

A 14-element DELTA array was successfully tested at sea on November 11 and 15, 1976 in 14,000 feet of water, northeast of Oahu, Hawaii. The tests were conducted in accordance with the Statement of Work contained in Contract Number N00039-77-C-0048 under the sponsorship of the Naval Electronics Command to test the DELTA array concept in regard to its applicability as a surveillance sensor. The specific technical objectives of the tests were: 1) Verification of array low frequency self noise characteristics in a deep water environment (level and directionality and 2) Verification of array geomtry and azimuth stability over an extended period. The DELTA System is a deployed, passive, low frequency hydrophone array designed to provide extended ASW detection capability to surface ships without placing restraints on speed or maneuverability. Its detection performance benefits by the inherent low flow-noise of a deployed system which is essentially motionless in the surrounding water. The test array was a linear string of 14 hydrophones, spaced 125 feet apart to permit acoustic data processing with the existing LAMBDA Processing System at Naval Underseas Center, San Diego. Other configurations have been investigated previously, and the test configuration is not necessarily representative of an optimum operational array.

The test results showed actual ship targets at ranges over the horizon and at frequencies starting below 7.5 Hertz. In addition, the 18 to 24 Hertz band exhibited regular signals which were assessed by NUC, San Diego as seismic profiling activity off the coast of Northern California at more than 2000 nautical miles. Several lines were judged to emanate from internal self-noise of the array, particularly at 100 Hertz. Post sea test analysis showed that the 100 Hz line was caused by the sonobuoy RF link and the 147 Hz line was due to a recorder malfunction. In summation all of the test objectives were achieved.

Section I

TECHNICAL BACKGROUND AND OBJECTIVES OF THE SEA TESTS

LMSC has been developing the DELTA Array concept on its own resources since 1971 with some assistance from ONR, NUC San Diego and NAVSEA 06H2/PMS304. The deployed DELTA Array is a large aperture, passive, horizontal array which can measure low frequencies (below 15 Hz) as well as higher frequencies (to 600 Hz). The array is suspended in the water column using a unique deployment technique which keeps it tensioned in the proper orientation (see Figure 1). The suspensioning method virtually eliminates flow noise from the system, allowing high signal-to-noise ratios in the low frequency spectrum.

Arrays built on 1974 and 1975 LMSC Independent Development projects have been tested at sea on many occasions. Many noise mechanisms have been identified and removed from the sensor output. Figure 2 indicates the progress made in array performance since March 1974.

Previous tests had established the feasibility of the DELTA concept of a quiet deployed array for low frequency detection, the effectiveness of the methods for streaming and recovering the array in timely fashion, the adequacy of controls for depth-keeping and maintaining array geometry, and the physical integrity of the deployed array. The present sea test was to determine performance and physical behavior at a deep-water, open ocean site, as a preliminary demonstration of the applicability of the DELTA concept for a Surveillance Sensor.

DELTA ID ARRAY CONFIGURATION

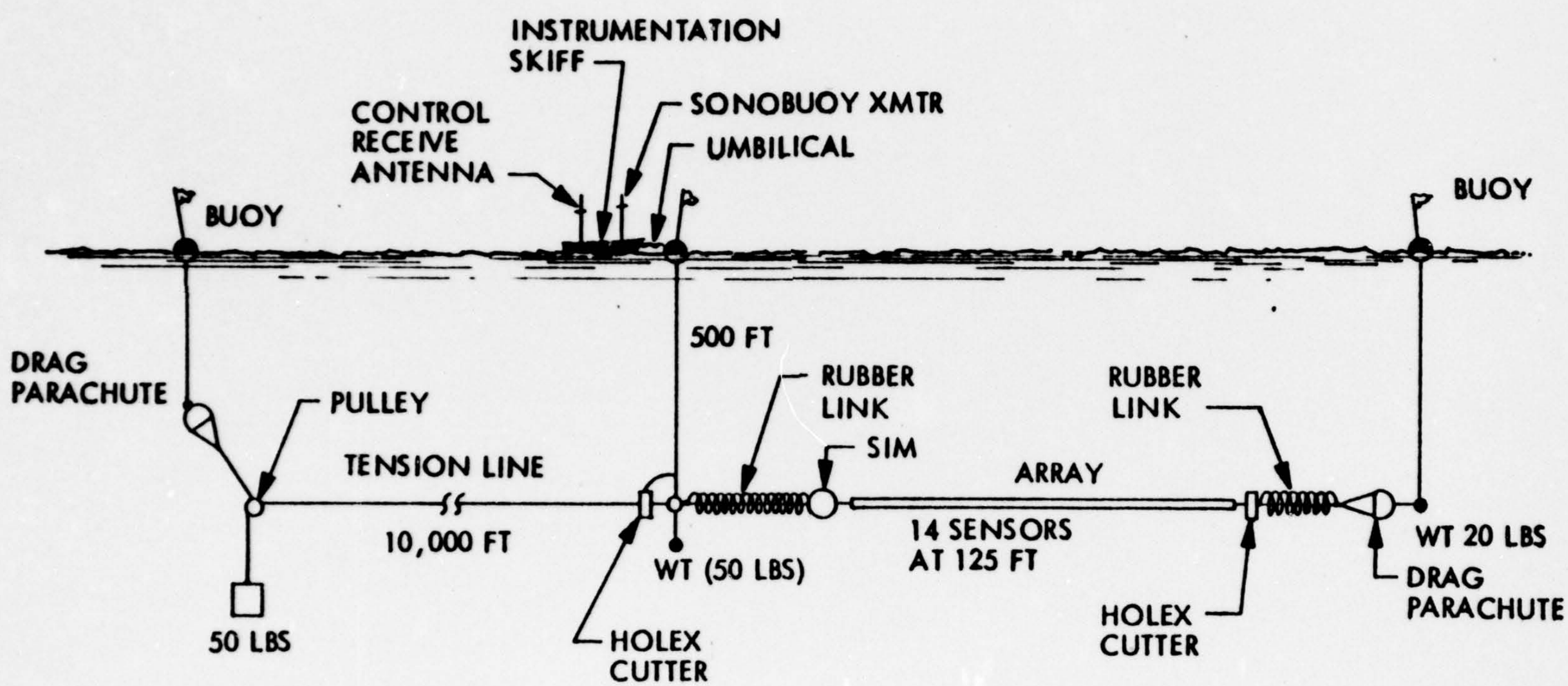
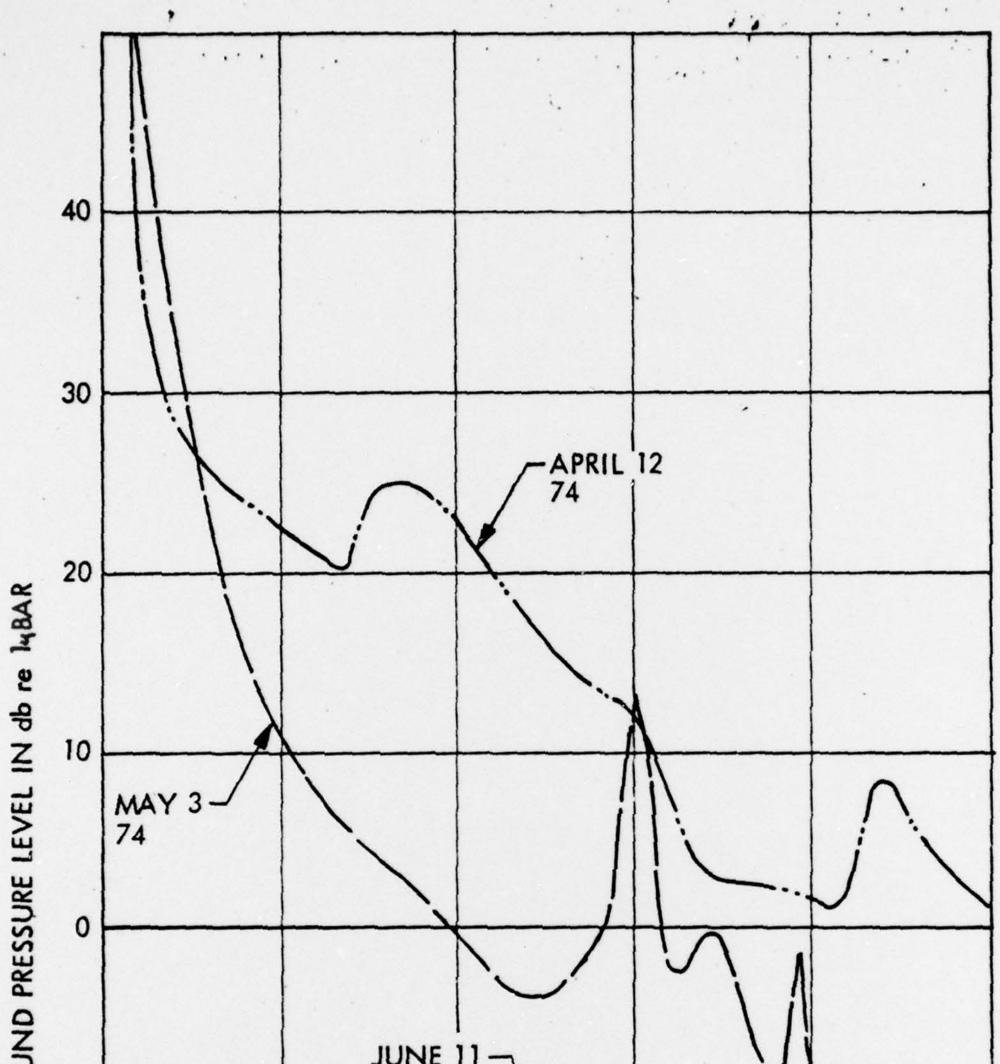


Figure 1



40
30
20
10
0
-10
-20
-30
5
10
15
20
25
FREQUENCY IN Hz
SOUND PRESSURE LEVEL IN db re 1μBAR
APRIL 12
74
MAY 3
74
JUNE 11
74
FEB 75
JULY 76
WENZ LIMITS OF
PREVAILING NOISE

Figure 2

Section II

TEST OPERATIONS

ARRAY CONFIGURATION

The configuration of the 14-hydrophone array is shown in Figure 1. The array consists of 14-hydrophones spaced 125-feet apart to permit processing of acoustic data by the LAMBDA Processing System located at NUC, San Diego. The 125-foot array sections are made of a special hose using radial and longitudinal strength members with OZEX extruded over them. Each array section is modular, permitting ease of repair or replacement, if required. The connection point between sections at each hydrophone location is by means of stainless steel bands which are clamped to a coupler. The array is ballasted for neutral buoyancy by filling each section with the proper amount of a high grade kerosene fluid (Shell-Sol). Fluid blocks in each array section prevent the Shell-Sol from one section entering another. The array has a breaking strength of over 2000 pounds. Signal wires, power leads and other conductors are encapsulated within the array strength member with a connector at each end of the 125-foot section to connect with the next section.

The array is designed for a deployment depth of 500-feet using a parachute mooring and tensioning system. On the right side of Figure 1, a surface buoy supports a 500-foot riser line attached to the crown of a drag parachute (30-foot diameter). A 10-pound weight is also attached to the crown of the parachute for depth control. A 100-foot long rubber compliant link is connected between the parachute shroud lines and the 1625-foot long hydrophone array. A surface isolation module (SIM) which entraps about 500 pounds of water is attached to the other end of the array to keep surface wave induced motions from reaching the array. A 200-foot long compliant rubber link is attached between the SIM and the weight at the bottom of the cable which leads to the instrumentation skiff. The compliant links and SIM effectively isolate the hydrophone array from wave action and other mechanical disturbances. An instrumentation skiff is attached to the data buoy. The tension

line is a light braided nylon line varying between 3000 and 10,000-feet in length (depending on water depth). This line is attached to the weight at the bottom of the cable and passes through a pulley block to a free falling weight. The shroud lines of the tension parachute are attached to the pulley which supports the lead weight. The crown of the tension parachute is attached to a 500 foot riser line to a surface buoy. As the weight free falls it pulls the two parachutes together at a rate of .4 ft/sec., making possible an operational cycle of about seven hours before the weight must be recocked.

ARRAY SENSORS, ELECTRONICS AND INSTRUMENTATION

There are 28 AWG 26 conductors in the array: 14 signal, 3 power, and the remainder for parachute cutters, depth sensors, accelerometers and self-calibration purposes. The data from each hydrophone are transmitted to the skiff by the signal wires in analog format and recorded on a 14 channel FM tape recorder. The hydrophone is radially poled, high capacitance air backed and mounted external to the array. Each hydrophone has a sensitivity of -95.6 dB $\pm$.5 with a flat response to 20 KHz.

Each hydrophone used in the array has been checked by the vendor before shipment for sensitivity and certified as to performance. Preamplifiers at each sensor give precisely 30 dB gain. Array gain in the instrumentation skiff is 30 dB fixed gain and 35 dB variable gain (in 5 dB steps) to make output levels consistent with the ocean noise field. The gain controls in the skiff can be varied manually or by remote control via a radio link. The array has a self-calibration capability which is accomplished by means of a 21 Hz oscillator of known signal strength. When the calibration signal is inserted to each hydrophone station, the signal output of each hydrophone preamplifier can be measured precisely to $\pm$.5 dB. High pass and low pass filters are placed in the circuit of each hydrophone pre-amp with pole points placed at 5 and 155 Hz. Low pass filters are necessary at the high end of the frequency band to keep out signals generated by high energy sonars such as the SQS-26. The high pass filters at 5 Hz are used to block first order wave pressure effects and seismic energy. Remote control from the monitoring platform RV Sea Quest permits varying array gain and continuous monitoring of one channel of omnidirectional data and broad-beam data by means of sonobuoy transmitters and receivers.

With 14-hydrophones at 125-feet spacing, the expected array gain is 11.5 dB at 20 Hz.

HANDLING EQUIPMENT

The handling equipment used at the present time is very basic but functional. The array is highly flexible permitting stowage in a bin 3 ft. x 4 ft. x 3 ft. The array is paid out and hauled in on a dual sheave hydraulic winch which weighs 950 pounds. The haul in rate is 5 ft/sec. The winch has a maximum tension of 400 pounds, to preclude high loads being placed on the array. A photograph of the handling equipment is shown in Figure 3. For ease of handling upon recovery, a guillotine cutter mechanism is activated to separate the array from the parachutes. After the array and instrumentation skiff are recovered, the parachutes and associated line are recovered in a separate operation.

TEST SITE

The test site selected for both deep ocean tests was about 35 nautical miles northeast of Oahu in a water depth of 14,000 feet. Figure 4 shows the test site location. The original plan was to use the semi-submersible Platform Ship (SSP). Unfortunately, the propeller reversing mechanism for both propellers failed a few days before the DELTA test period and the SSP was not available.

The Hawaii Laboratory at the Naval Undersea Center provided a 72-foot long torpedo retriever as a substitute boat. Several minor modifications were required to make the boat suitable for DELTA deployment and retrieval. The starboard torpedo well was modified to accomodate the instrumentation skiff. The port torpedo well was decked over to carry the DELTA Array and recovery winch. The torpedo retriever was not fitted out to remain at sea overnight, which restricted test site selection and test duration. In addition, the narrow entrance through the coral reef at Kaneohe Bay was not lighted making necessary a daylight return through the coral reef.

By getting underway at 0530 and using maximum speed to and from the nearest deep water, it was possible to schedule a four hour data take period for each test. Return to Kaneohe Bay was scheduled for sunset.

Figure 3

NAVELEX 320 DEEP OCEAN TEST SITE

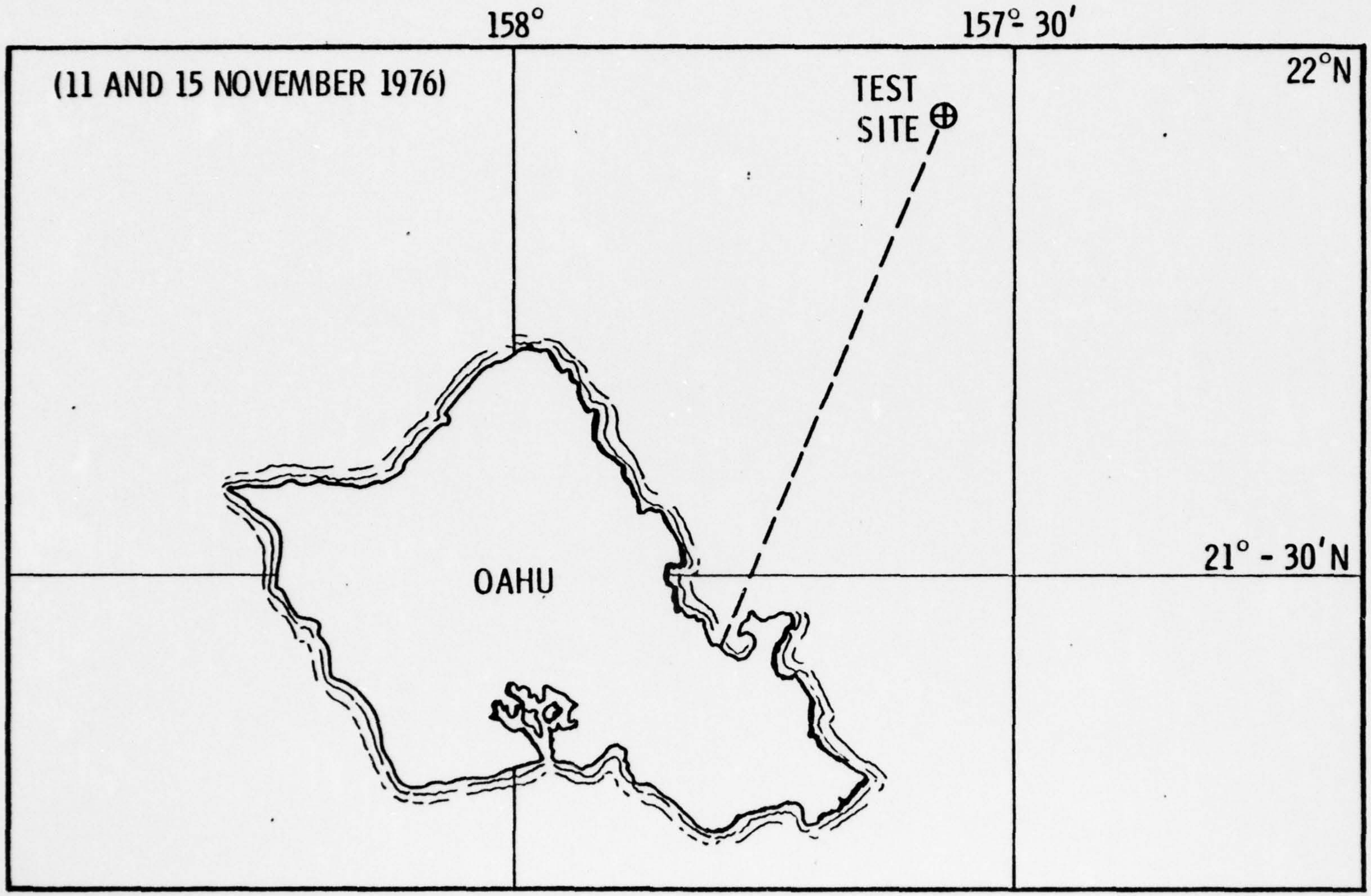


Figure 4

The first deep sea test was conducted on 11 November 1976. The weather was about normal for this time of year. Trade winds were out of the northeast at 12 to 16 knots with a six to eight foot sea running. The array was deployed at 21° -56' N lat and 157° -34' W long on a deployment course of 070° magnetic (059° true).

Deployment commenced at 0920 and was completed at 1005. Deployment operations went smoothly. The array was set for a depth of 500 feet. A timer in the instrumentation skiff was set to cut the array loose from the two parachutes at 1320 for recovery operations. At 1320 the skiff was pulled into the torpedo recovery well using manpower. The array was recovered using the winch. The array parachute was recovered next, followed by the tension parachute. Transit through the Kaneohe Bay coral reef was made at 1735.

Heavy weather was predicted for the next few days so a tentative sea test was scheduled for Monday, November 15, 1976. The torpedo retriever got underway at 0537 for the test site. Winds were light and variable; however, as the torpedo retriever proceeded out from under the lee of Oahu, ten to twelve foot waves out of the northwest were encountered. Deployment commenced at 0856 and was completed at 0940. The array was deployed on a course of 050° magnetic (039° true). The wind in general was light and variable except for the period of 1110 to 1210, when a rain squall passed through the area.

Recovery operations commenced at 1310. Recovery of the instrumentation skiff, array and the array parachute was surprisingly easy in spite of the ten foot waves. The tension parachute required higher than normal winch pull. When the parachute broke the surface, a large shark was found to have some of the tension parachute caught in his mouth. The shark could not be dislodged, so it was decided to take the shark aboard in the torpedo well astern of the instrumentation skiff. Fortunately, the shark had suffocated from the parachute in his mouth. It required about one hour and fifteen minutes to get the shark in the torpedo well because of its large size and the high waves.

The shark proved to be a new genus which had not been seen before, and was turned over to the University of Hawaii for study.

Return transit through the coral reef was made at 1740.

MEASUREMENT EQUIPMENT AND TECHNIQUES

Azimuth stability of the array was monitored from the torpedo retriever, using the pelorus, and held within 2°. Array depth was not directly measured, but subsequent beam-forming success showed that the 500 ft. design depth was held within 40 to 50 ft., as in previous trials.

Acoustic measurements were recorded in analog format on a 14-channel Honeywell FM (5600C)tape recorder, located in the skiff. The analysis equipment included a dual channel Spectral Dynamics 360 spectrum analyzer; a single channel Spectral Dynamics 330A Spectroscope and Hewlett-Packard x-y plotter for narrow band analysis of single hydrophone output; and a Sanders SA240 Spectrum Analyzer coupled to a White Instrument 4000 series Equalizer and E.P.C. 2200 Precision Recorder for LOFAR-gram study. A known 21 Hertz signal was injected into each hydrophone every 20 minutes to calibrate the array and its instrumentation, and to check operation of the equipment.

Section III
TEST RESULTS

ANALYSIS TECHNIQUES

Single Hydrophone Analysis: The single hydrophone spectrum analysis was performed over a 0 to 25 Hertz, and 0 to 100 Hertz range. The filter band-width was 0.15 and 0.6 Hertz respectively. All plots have been corrected to Db re 1 Pa/Hz$^{1/2}$. The averaging periods were 320 seconds and 160 seconds. The longer the averaging period, the smoother the response curve, as the noise transients tended to be eliminated with the longer period.

The individual hydrophone analysis checks the consistency of response between hydrophones along the array.

Dual Cross Spectrum Analysis: The Dual Cross Spectrum Analysis was performed over three ranges: 0 to 10, 40 and 150 Hertz. The basic purpose of this analysis was to determine the direction of the sources of the signals and to distinguish between acoustic signals, mechanical vibrations, and electrical self-noise within the system. The Spectral Dynamics 360 unit provides information on phase and coherence between two signals. The phase measurements indicate the differences in phase over the full frequency band between adjacent hydrophone pairs. The odd hydrophones are used as the reference hydrophone in each analysis.

The level of coherence is determined by the signal to noise ratio of the signals and the consistency of the phase relationship. In other words, the higher the correlation and the more constant phase, the higher coherence. The coherence is important because it reflects the confidence in the point indicated on the phase plot, hence high coherence would indicate a good phase reading.

LOFAR-gram Analysis: We selected only the hydrophone responses of position 13 on the eleventh, and 2 and 13 on the fiteenth. These analyses were limited by the availability of high demand NUC equipment.

The analysis ranges were selected to cover 0 to 40 Hertz and 0 to 160 Hertz. These ranges provide very narrow band analysis, .05 Hertz in the lower frequency range and 0.20 Hertz in the upper. This provides full coverage over the entire pass-band of the array. Channel 13 was selected for the LOFAR-gram analysis based on the preliminary SD 330A analysis.

QUANTITATIVE RESULTS

The data from the two days of testing has been analyzed by three different methods, and the results indicate that the data are valid. Most of the signals have been identified. There are some lines which as yet are unexplained. The methods of analysis consist of single hydrophone narrow band spectrum analysis, dual hydrophone cross-spectrum (phase) analysis, and single hydrophone LOFAR-gram analysis. The beam forming ability of the array has been partially demonstrated (using phase analysis) by determining directions of several signal sources. Also determined has been the presence of some 0-5 Hertz mechanical disturbances on a few of the end hydrophones.

The plot in Figure 5 shows the typical sound spectrum levels over a 0-100 Hertz range taken on November 15, 1976. Various portions of the spectrum can be attributed to several different sources as noted on the figure. In the 15 to 23 Hertz area, the two levels denote the presence and absence of a source assessed as seismic profiling. The series of peaks appearing from 30 Hertz to 68 Hertz are almost all harmonically related to a fundamental at 7.5 Hertz. The 30 Hertz peak represents the fourth harmonic, 37.5 Hertz the fifth and so on, then disappearing after the ninth harmonic. This series of peaks is typical of signals originating from large ships. The data on the eleventh showed similar related peaks, but originating at a different fundamental frequency of about 8 Hertz. All these lines are assessed as valid targets at undetermined ranges.

NAVELEX 320 DEEP OCEAN TESTS

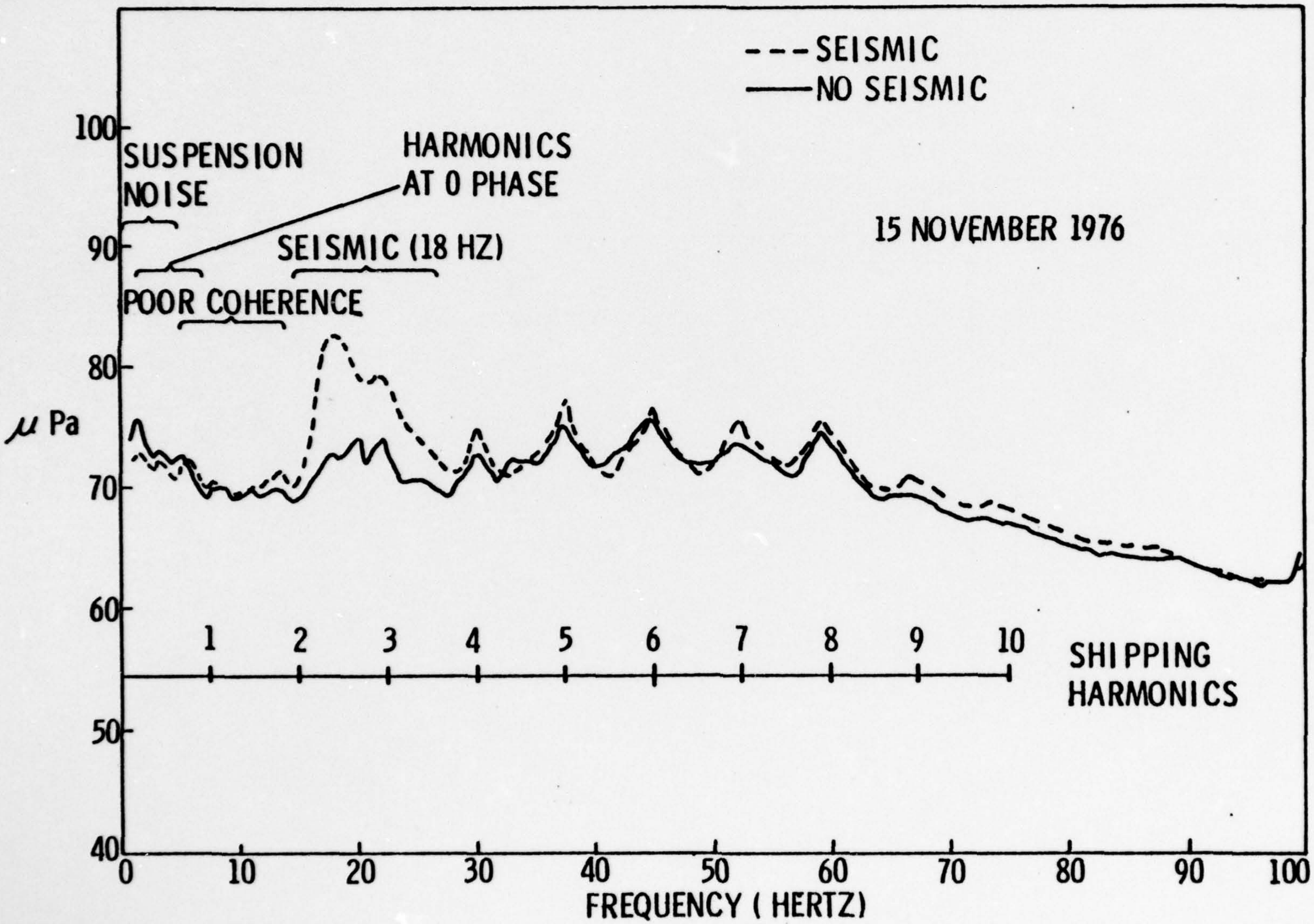


Figure 5

In the plots of 1 to 10 Hertz, several more harmonically related sets of peaks (or lines) were revealed. The LOFAR-grams show that some of these lines vary linearly in frequency with time. At present, these lines have not been fully explained. The S.D. 360 cross spectrum analysis of these sets of lines generally indicate near 0 degrees phase shift, acoustically broadside signals, or possibly instantaneous electrical noise. A somewhat lower level of indicated coherence at these lower frequencies between hydrophones doesn't allow a very high level of confidence in these phase observations. If we had the ability to beamform with all 14 channels, it would greatly tend to resolve this type of data more accurately and to assess whether or not the noise possibly originates electrically.

There are some traces below 5 Hertz. The variation between the first four hydrophone sensor output levels and excessive phase shift (SD 360 analysis) indicate a mechanical origin of this noise. Generally, position 1 (hydrophone 1) exhibits the highest levels, then 2-3, 4-11, 5-10-14, 6-7 with 12 and 13 showing the lower levels. In the 140 Hz analysis range, some other lines appear. The 147 Hertz line is suspected to be an internal oscillation within the system. These and other lines have not been fully studied, as time and equipment have not permitted analysis.

Figure 6 shows average hydrophone data taken during the absence of seismic activity on the fifteenth. The data have been corrected for rolloff. The dashed lines represent ambient noise data recorded on the ACODAC system.* The ACODAC information was recorded at two test sites in the Eastern North Pacific central waters over several 24 hour periods. The upper curve is the deep sound channel (DSC) noise level and the lower one is the critical depth noise level. These depths are 2100 feet and 13,200 feet respectively. The ACODAC system does not suffer from any surface effects as it is a bottom suspended array, but it is subjected to the deep ocean currents.

In comparison, if the high level spikes from DELTA test data were removed, the DELTA Array would show lower ambient noise levels over all frequencies.

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*Ref. JASA November 1976

The range of ambient noise from the DSC axis to critical depth should represent the limits of expected levels over the entire water column. The DELTA System test site was located 600 miles further south than the southern ACODAC unit, and since the Northern Pacific shipping density is much greater than the South Pacific, some attenuation would be expected. The ACODAC tests show attenuations of:

Hz	$dB/kyd \times 10^{-3}$
12.5	3.6
25	2.9
50	2.4
100	2.6
200	4.5

These appear to be somewhat consistent with our levels.

The cross-spectrum analysis is summarized in the plots of Figures 7 and 8. These represent the tests of November 11th and 15th, respectively, and show the phase relationship between adjacent hydrophones over 2-1/2 minute averaging period. The plots are displayed as phase versus frequency; frequency being 0 to 150 Hertz along the x-axis. The y-axis (phase) is displayed as 0 degrees in the center with +180 degrees being the upper limit and -180 being the lower limit. It should be noted that a signal at exactly +180 or -180 can actually be displayed at either limit. For example, as a signal advances past +180 degrees and continues past it will then be shown as moving up from -180 at exactly the same angle and point where it went in at +180 degrees. When the acoustic signals originate at exactly broadside, the phase shift will be 0 degrees and that is displayed down the center axis of the chart. On the other hand, signals originating on the end-fire axis will be displayed on the maximum phase limiting line. This end-fire limiting line originates at 0 degrees and 0 frequency and crosses to $\pm$180 degrees at 20 Hertz. Since the hydrophone spacing is precisely 125 feet, and the lowest acoustic frequency (at end-fire) which could produce a 180 degree phase shift is 20 Hertz, i.e., for 125 foot spacing, no valid acoustic signal may exist to the left of the limit line nor can a continuum of frequencies, from a given direction, be shown as a line steeper than that of the limit line. Also, as a distant source is displayed, the line drawn representing that particular angle

ACODAC/DELTA AMBIENT NOISE MEASURUREMENTS

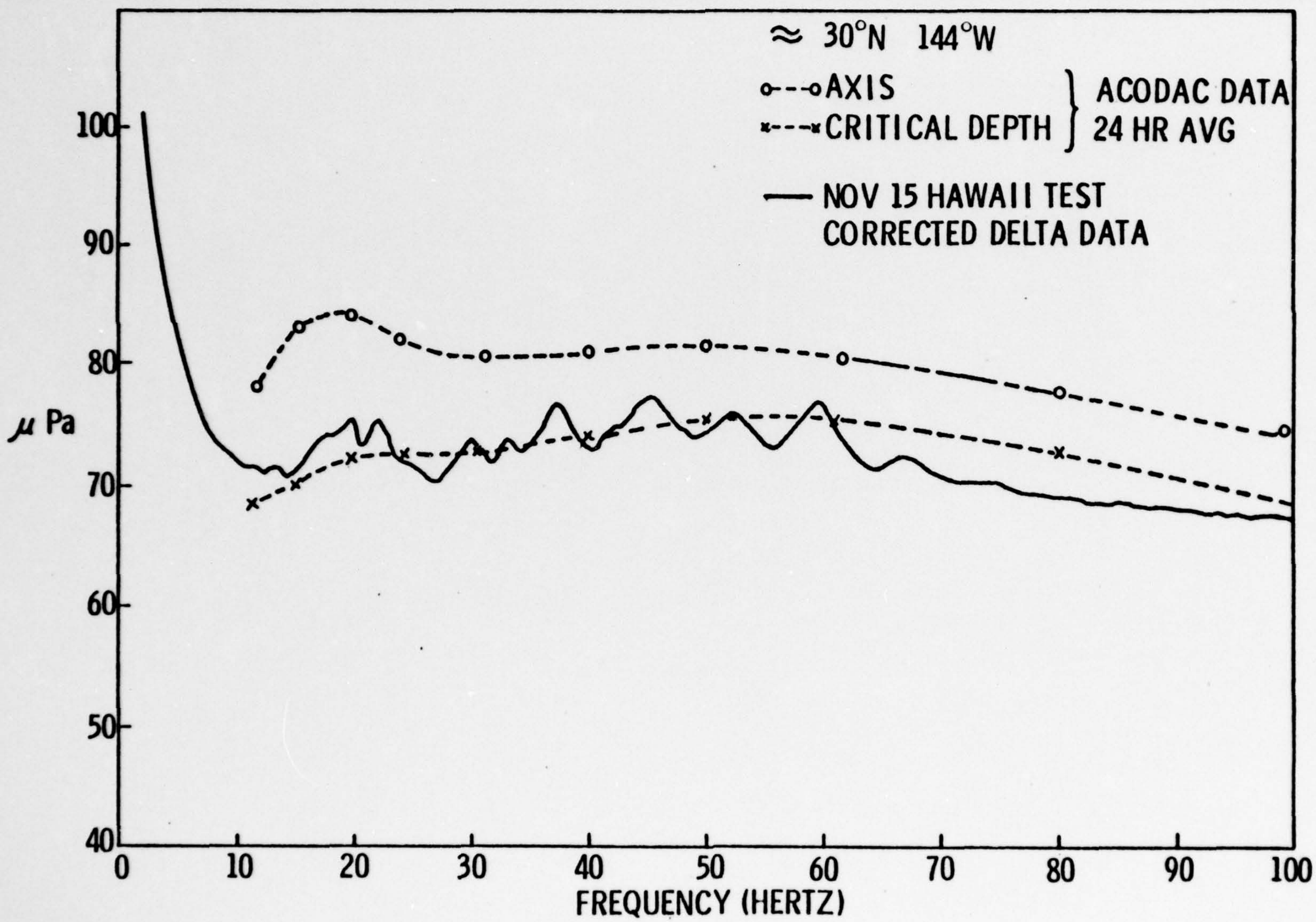

Figure 6

CROSS SPECTRUM ANALYSIS
NOVEMBER 11

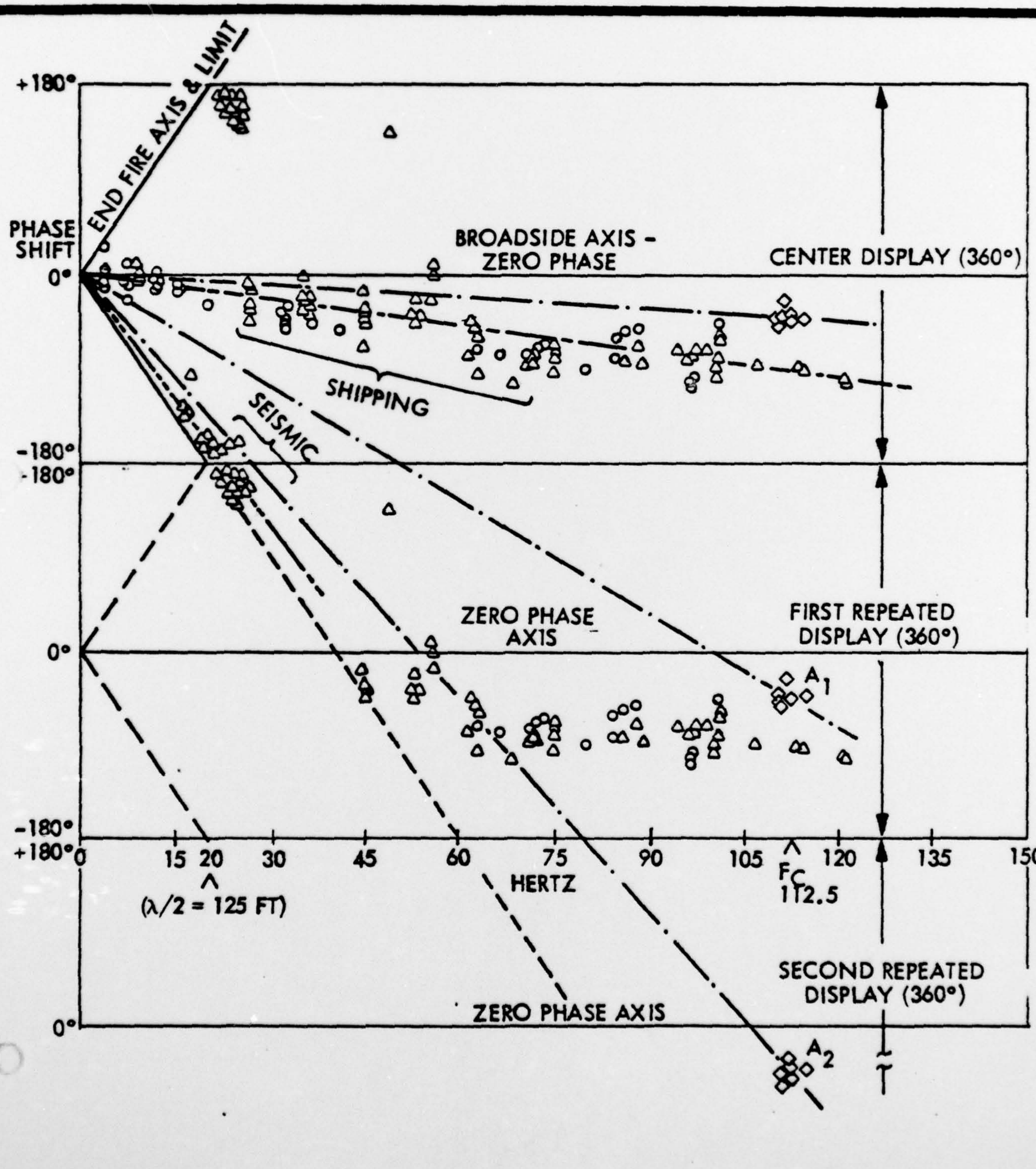

Figure 7

CROSS SPECTRUM ANALYSIS
NOVEMBER 15

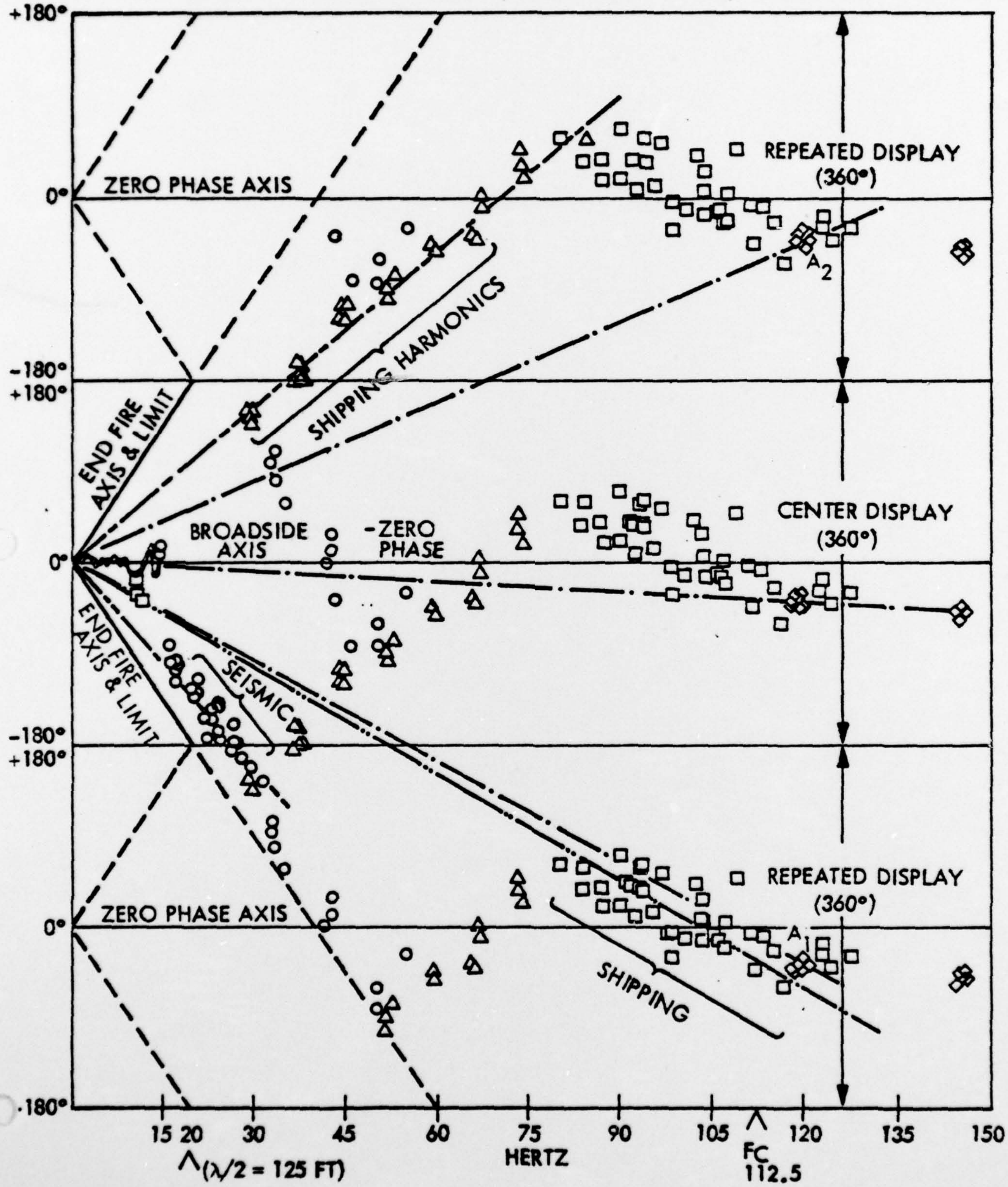

Figure 8

must intersect the 0 degree and 0 frequency point. This must also be true for any repeating line due to the ± 180 ambiguity.

The plot on November 11th shows a predominance of points along an average line (8° below broadside), corresponding to a source about -12.7° off of array broadside. This line of point is due to the stronger levels of many ships in that general direction. In the frequency range of the seismic source (15-23 Hertz), the points appear almost along the limit or end fire line corresponding to -84.5° from broadside (5.5° from end fire). Located below the broadside line at 112 Hertz is a group of points (A) which indicate a strong source with a consistent phase relationship. However, we are unable to tell from exactly which direction it originates. There are five different arrival angles which would satisfy the phase measurement due to the repeating nature of the phase display (example: points A1 and A2 are also at the same place).

The analysis of the November 15th date exhibits a different set of lines. The several different arrival angles are much more obvious with the greater separation of points. The seismic source (15-23 Hertz) indicates an angle of -76.5° from broadside. The shipping harmonics from 30 Hertz to 75 Hertz indicate a direction of $+65^{\circ}$ from broadside. Another line, 75 to 125 Hertz, appears at -48°. This A series of points is also present showing similar phase but at a different frequency. These points are due to array internal self noise representing a constant phase shift between hydrophone channels.

The array beam response, Figure 9, shows several of the actual arrival directions of acoustic signals which were indicated on the previous phase analysis plots. The axis of the array on the eleventh and fifteenth deployment was 059° and 038° respectively. Also, note on the figure, that for each particular arrival angle, two directions are actually indicated, each at the same angle. There is an ambiguity as to which broadside "side" the measurements are referenced to. This is typical of single linear arrays. On November 15th, one of the pair of lines points to the northeast shore of Oahu. This line would be the ambiguous line as there was actually no shipping traffic in this area and the other, pointing just beyond the north point, would represent the correct direction. However,

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(11&15 NOV 76)

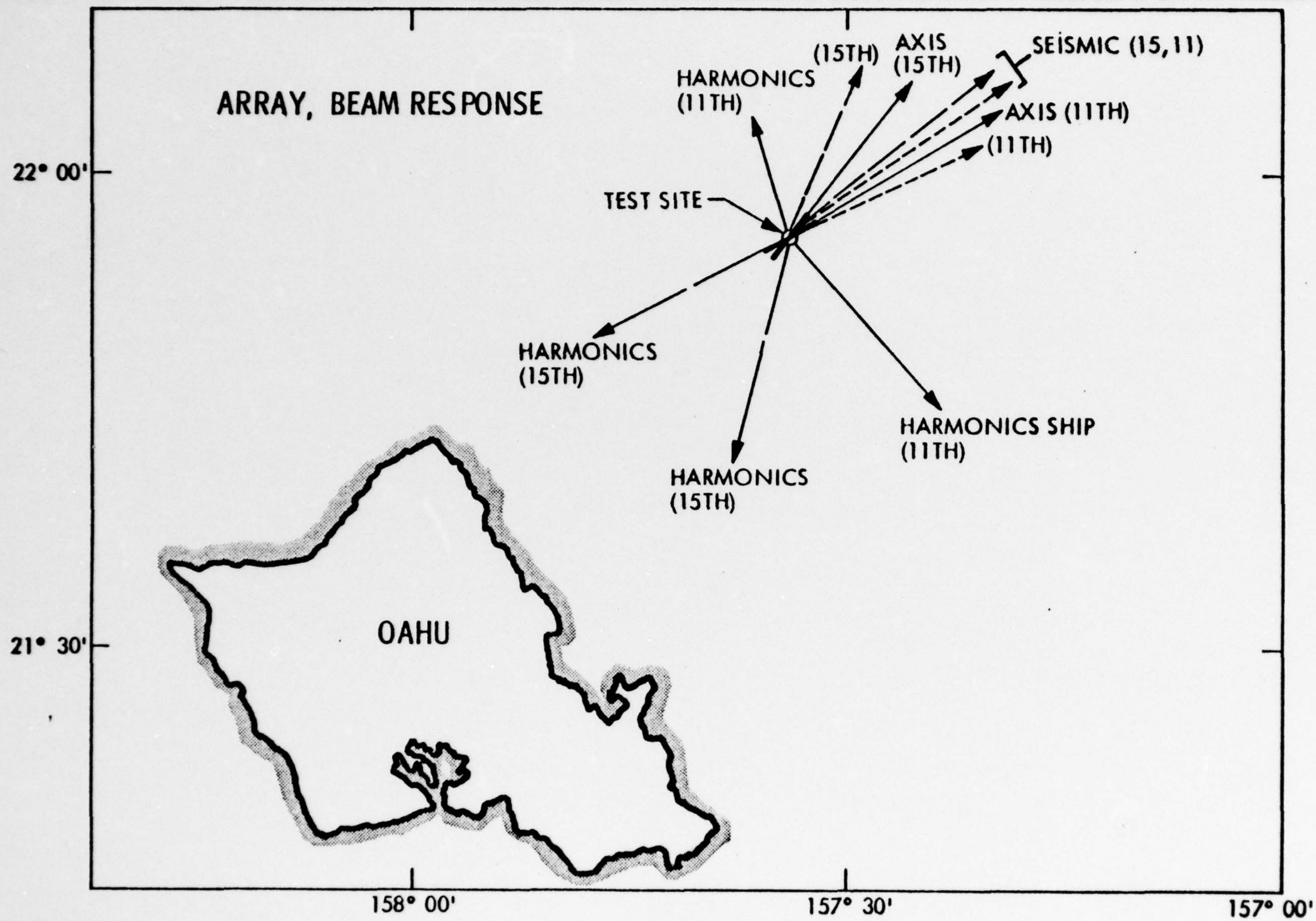

Figure 9

with the seismic information, even though four directions are indicated for the two days, only two of the lines are close enough, indicating that the correct direction was where these two lines almost coincide. This angle, approximately 55^{o} indicates that the seismic surveying source was on a line intersecting the northern coast of California. If beam-forming equipment had been available, these signals at the various arrival angles could use the array gain to increase their signal-to-noise ratios. This would tend to bring out more of the lines of these and of other distant targets presently obscured by the ambient noise levels.

The LOFAR-gram, Figure 10,is a record of the spectral variations with time of the narrow band frequency content of a single hydrophone from 0-160 Hz. As the level of signal in each frequency analysis band increases, there is a corresponding increase in darkness of the trace at that point along the frequency axis. This is exactly the same information as the SD 330A analysis, but plotted by varying the Z-axis and versus time. If one notes the differences at 15 to 27 Hertz in the traces at tape recorder footage readings of 1450 to 1500 feet and at 1540 to 1590 feet, this same difference has already been illustrated in Figure 5 in another form where the broken lines represent the same period of time where the seismic profiling impulses are present. Further examination of the LOFAR-gram reveals that the seismic profiling source is being fired regularly every 40 seconds with an occasional pause about every 5-10 minutes. The pulse is centered at 18 Hertz, which is typical for explosive gas guns used in seismic work. These pulses were observed periodically throughout both days of the tests. In both LOFAR-gram traces, ship harmonics manifest themselves as the continuous equally spaced vertical lines. The occasional streaks horizontally across the trace are representative of individual noise bursts.

At 147 Hertz, running the full length of the trace, is the line generated within the array electronics which is not an acoustic source. The sources of these 147 Hz and 100 Hz lines have been determined to be a malfunction in the tape recorder and the RF link respectively.

A low frequency gram Figure 11,is plotted from 0 to 40 Hertz. In this range, with narrower filtering, the signals below 15 Hertz are brought out. A one-third

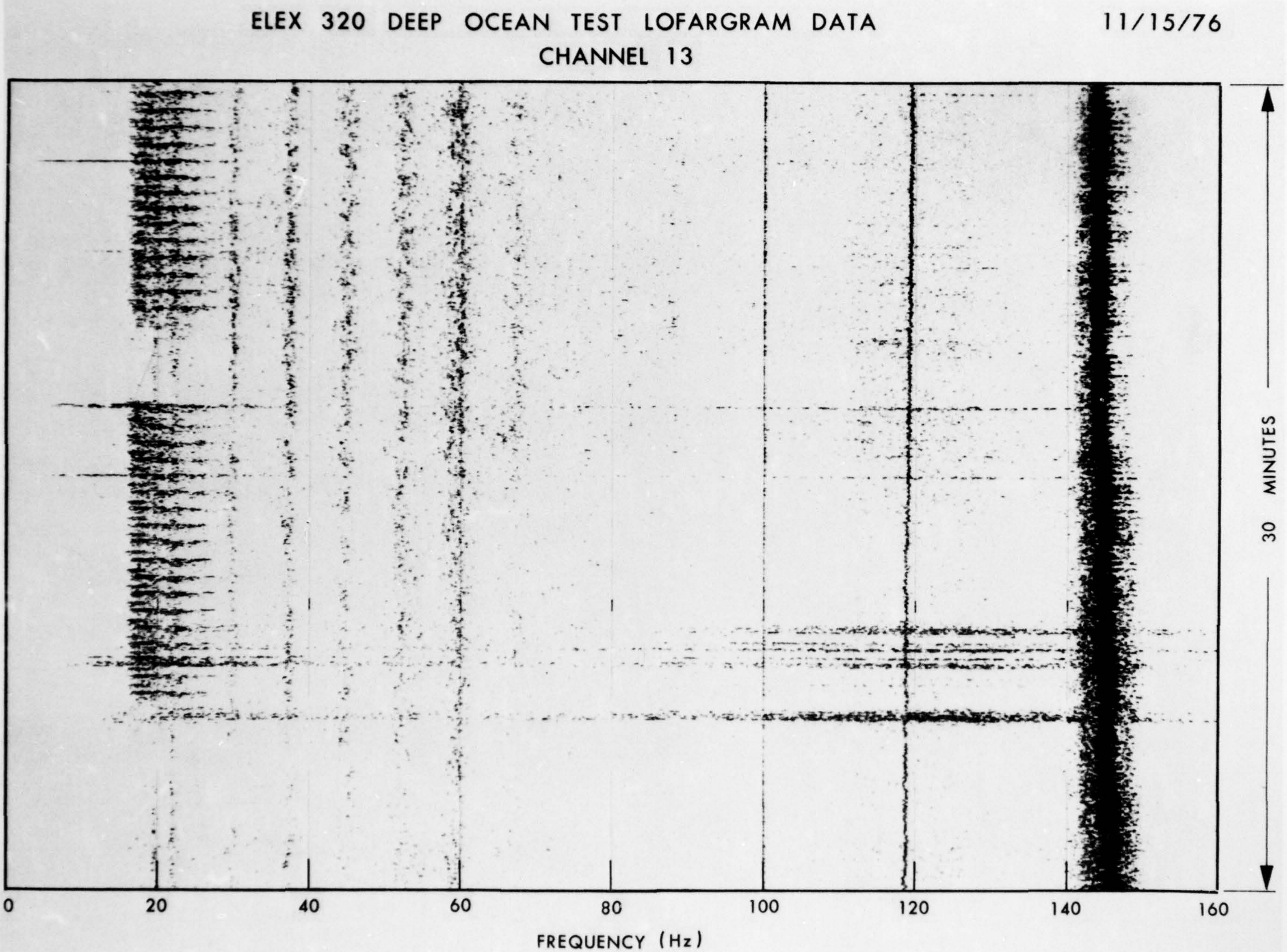
ELEX 320 DEEP OCEAN TEST LOFARGRAM DATA
11/15/76
CHANNEL 13
30 MINUTES
0
20
40
60
80
100
120
140
160
FREQUENCY (Hz)

Figure 10

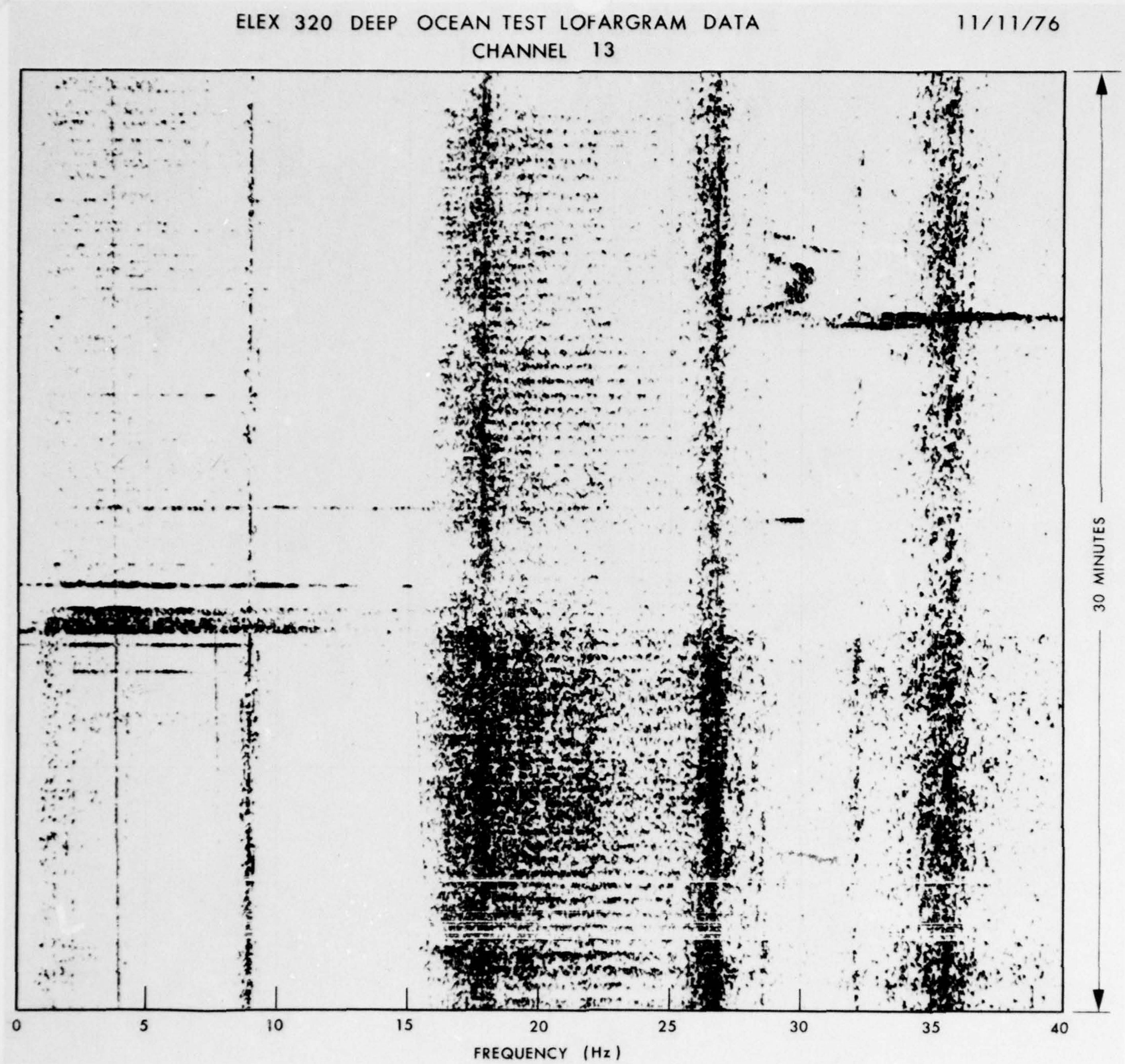
ELEX 320 DEEP OCEAN TEST LOFARGRAM DATA
11/11/76
CHANNEL 13
30 MINUTES
0
5
10
15
20
25
30
35
40
FREQUENCY (Hz)

Figure 11

octave band equalization network was used during the 0-160 Hertz analysis to bring up the electrically rolled-off high frequency signals, this process removed the signals below 15 Hertz because of the input network. In this narrow range analysis, the equalization network was not required, allowing the 0-15 Hertz signals to be displayed.

One can clearly see one line at 3.75 Hertz and, very faintly, its second harmonic at 7.5 Hertz. Two other very obscure lines at 1.5 and 2.25 Hertz are probably probably the second and third harmonics of an unobserved 0.75 Hertz fundamental. These two lines are steady in frequency whereas the two at 3.75 and 7.5 Hertz increase linearly with time. A much stronger and broader line that is fairly steady can be noted just below 9 Hertz, and faintly, a possible second harmonic within the seismic hump. Throughout the LOFAR-grams there are noted many lines and their harmonics which overlap and fade in and out with time. Additional analysis in a 0 to 8 Hertz band (0.01 Hertz bandwidth) could be used to enhance even the more obscure lines.

The sets of lines and individual lines that are steady in frequency are probably screw beats and reduction gears of large ships. The set of lines which steadily vary in frequency with time have not been explained.

If the array had been operated with a beamforming network such as the LAMBDA processor and then each beam had been analyzed for spectral lines, many questions could be answered. The beamforming would tend to separate the target lines and their harmonics from others at the same frequency which are actually coming in from totally different directions.

GENERAL OBSERVATIONS

The low frequency noise characteristics observed in deep water do not differ much from some of the better measurements obtained off San Diego, in regard to individual hydrophone comparisons. We have no LOFAR-grams of previous data to compare, nor has there been as comprehensive of a phase analysis, except possibly

for a short LAMBDA-FRAZ analysis of some data from an October 14th sea test. These latest data appear to be very good with no seriously interfacing anomalies.

The LOFAR-gram analysis was made for the first time on the Hawaiian data, and the results indicate that this type of equipment is essential for any further analysis and re-analysis of past data, since the noise, is dominated by many distant and constantly changing sources. If an analysis is made at a particular period of time, the results may differ by 5 to 10 dB in a measurement. It was found using the LOFAR-gram that significant low noise periods existed within our normal averaging periods. Additionally, these normal analysis periods could include some very noisy portions, further biasing the measurement.

The periodic nature of the seismic pulses would not have been observed without the historical record that the LOFAR-gram provides. It would not have been possible to identify the periodic nature of the seismic profiling source on the SD 330A, SD 360, or even the LAMBDA-FRAZ unit unless the LOFAR-gram was used.

The array's performance above 5 Hertz is very good. In the 0 to 5 Hertz area two-thirds of the array shows low ambient and self noise levels.

The several non-acoustic (i.e., 100 and 147 Hz) lines observed in the data appear not to degrade the array beamforming capability. Post sea test analysis showed that the 100 Hz line was caused by the sonobuoy RF link and the 147 Hz line was due to a recorder malfunction which has been corrected.

Section IV

CONCLUSIONS

- The array can be streamed and recovered in the open ocean. (Sea State 4 was the highest observed,)
- The array maintains azimuth within 2^{o} and depth to less than ± 50 ft.
- Seismic profiling tests in the 20 Hertz band were detected at over 2000 nautical miles.
- Over-the-horizon ship targets at unknown ranges were detected at low frequencies and higher harmonics (fundamental frequencies 7.5 and 8 Hz.)
- The array has internal electronic noise spikes at 100 and 147 Hertz.
- The array has some unexplained self noise below 5 Hertz.
- Array performance at low frequencies (below 7.5 Hz) is not believed to be ambient limited.
- The array acoustic data can be beam-formed with the addition of a suitable processor; demonsrated after-the-fact with LAMBDA processor.
- The long-range, low frequency detection capability of a deployed array has been verified in over two years of testing at sea.

Section V
RECOMMENDATIONS

Based upon the knowledge gained from this project and for the purpose of strengthening the technical base of deployed array technology it is recommended that a new experimental array be built and tested. This array would have instrumentation (strain gages, 3 axes accelerometers, depth sensors) that would provide a better understanding of array dynamics at low frequencies. A test program would be initiated to provide for direct comparisons of low frequency self noise with these sensors to determine the effects of:

a. transverse acceleration
b. improper ballasting
c. tension transients
d. changes in tension on self noise
e. a large surface buoy versus a small one

In addition to gaining a better understanding of array dynamics the recommended experimental program would have the following objectives:

a. Elimination of self noise below 5 Hz.
b. Beam forming of acoustic data on existing GFE.
c. Demonstrate improved handling/packaging capability.
d. Remove 100 and 147 Hz lines observed during the Hawaiian tests from sensor outputs
e. Measure acoustic data with a calibrated source level (near and far field).
f. Continue to demonstrate array stability and depth control.
g. Provide a firm technical justification for advanced development of the deployed array concept toward ultimate deployment of a fully operational system.

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